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OWENS GORGE PROJECT

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POWER DIVISION

{Discussion open until November 1, 1955}

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OWENS GORGE PROJECT[1]

Samuel B. Morris,[2] M. ASCE

In presenting this paper describing the Owens River Gorge Hydroelectric Project of the Los Angeles Department of Water and Power, I should like to review briefly the events which led to the Department constructing this 112,500 kilowatt development 260 miles north of the City on the east slope of the Sierra Nevada Mountains.

INTRODUCTION

The City of Los Angeles first entered upon the municipal ownership of its water works in February, 1902, when it acquired the works of the Los Angeles City Water Company. This was during one of the most critical dry cycles which began in 1893 and continued to 1904. The City had grown from a population of 50,000 in 1890 to 100,000 in 1900. The far-seeing leaders of that time found that the water available from the Los Angeles River and other local sources was inadequate to meet the demands of the growing city. They proposed a 240-mile aqueduct to bring water from the Owens River which drains the east side of the Sierra Nevada Mountains.

The first municipal bonds for the Los Angeles-Owens River Aqueduct were voted in 1905 and the project was constructed from 1907 to 1913, when water was first delivered into the San Fernando reservoirs on the northerly outskirts of the City.

The first hydroelectric plant constructed by the Department was built in 1908 on Division Creek in Owens Valley. This and other plants on Division Creek and Cottonwood Creek in the Owens Valley were constructed to furnish power for construction of the aqueduct. After completion of the aqueduct these plants continued in operation to provide electricity for the towns in Owens Valley served by the Department.

The first surveys for the Owens River Aqueduct indicated that approximately 100,000 kilowatts of hydroelectric power could be constructed along the aqueduct, making use of its fall of about 2,000 feet. Shortly thereafter studies also indicated a like amount of power could be produced in the Owens River Gorge where there is a fall of 2,300 feet in a distance of about 18 miles.

Bonds were first voted in 1910 for the construction of the first hydroelectric plants along the aqueduct, principally in San Francisquito Canyon, and in 1911 the citizens voted by about 8 to 1 to have this power distributed by the City of Los Angeles to the homes, business and industry of Los Angeles. Thus it was that opportunities for development of hydroelectric power along

1. Paper presented at the San Diego meeting of the American Society of Civil Engineers, Power Division, February, 1955.
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the Los Angeles Owens River Aqueduct, with popular vote of the citizens of Los Angeles, placed the City in the electric utility field as well as in the supply and distribution of water. The Department, created to provide both water and electric service, was later renamed the Los Angeles Department of Water and Power.

With growth to a present population 20 times that of the year 1900, water and power demands have grown and continue to grow, with power demands more than doubling each decade since the Department installed its first pole in 1916 and began operation of its San Francisquito power plant in 1917.

Physiography

Returning to the description of the Owens River Gorge Project, upon which construction began in 1947, the Owens River Gorge is located approximately 260 miles north of Los Angeles, lying between the Sierra Nevada mountains on the west and the White Mountains and the Inyo Mountains on the east. In relatively recent geologic time, successive lava flows poured down from the north over an ancient eroded surface of granitic rock lying between these two mountain ranges, and extended to within about 10 miles north of Bishop before it cooled and solidified. The volcanic materials vary in density from unconsolidated volcanic ash through soft rhyolite to very hard rhyolite and basalt. In the aggregate, these lava flows have great thickness. The surface is a relatively flat mesa, sloping gently to the south. The Owens River flows in an irregular v-shaped gorge through this high volcanic tableland. The gorge varies in depth from 700 feet at the north end to 200 feet at the south end with a fall in the river of some 2,300 feet in 18 miles. The gorge is very narrow and for much of its length the walls rise precipitously from the stream bed. Core drilling along the tunnel lines and exposed rock in the gorge indicate that there is an old granitic ridge running east and west in the northern part of the area and extending to elevations above the tunnel grade.

The Owens River at the gorge drains an area of 221 square miles of the east slope of the Sierra Nevada Mountains. Its tributary streams rise at altitudes up to 13,000 feet, falling rapidly to discharge into the river at elevations of some 7,000 feet. Below the gorge, similar streams enter the main river at elevations of the order of 4,000 feet. The Owens River aqueduct with its intake near Independence at an elevation of 3815 feet delivers water to the San Fernando reservoirs in the upper San Fernando Valley at an elevation of 1135 feet. It is these differences in elevation which provide suitable drops of hydroelectric development along the aqueduct and within the Owens River Gorge.

During the 1930's, in order to increase the flow of the Owens River aqueduct, the Department purchased lands and rights and extended its diversions as far north as Leevining Creek, 338 miles north of Los Angeles, actually farther north in latitude than the City of San Francisco. Streams tributary to Mono Lake were diverted into the headwaters of the Owens River by means of the Mono Basin extension of the aqueduct, which included construction of the 12-mile Mono Craters tunnel. This increased the average flow available at the Owens River Gorge from 230 second feet to 405 second feet.

During this time the Department purchased several small hydroelectric plants from the Southern Sierras Power Company, predecessor of the California Electric Power Company, including the two Adams plants in the Owens River Gorge. This made possible the construction of Long Valley Dam above the Owens Gorge creating Lake Crowley, and the construction of the complete power development in the Gorge. Long Valley Dam is an earthfill dam of

Fig. 1 - Aerial photo showing the relative locations of the major features of the Power Project.

1,045,000 cu. yds. and has a height of 182 feet above bedrock. It provides a storage capacity of 183,000 ac. ft. Future developments may include raising the dam 20 feet, which would raise the spillway crest to elevation 6801.5 feet, providing a total capacity of 315,000 ac. ft. Low water is at elevation 6700 feet. For purposes of design, an average water level of 6775 feet has been assumed with tailwater at the lowest power plant in the Gorge at elevation 4400 ft. providing a gross average available head of 2375 feet.

Pleasant Valley Dam now being constructed 14,000 feet downstream from the lower or control power plant in the Gorge, will create a reservoir of 3900 acre feet. Tinemaha Dam and Reservoir which has a storage capacity of 16,600 ac. ft. is located thirty-five miles below the Gorge and six miles above

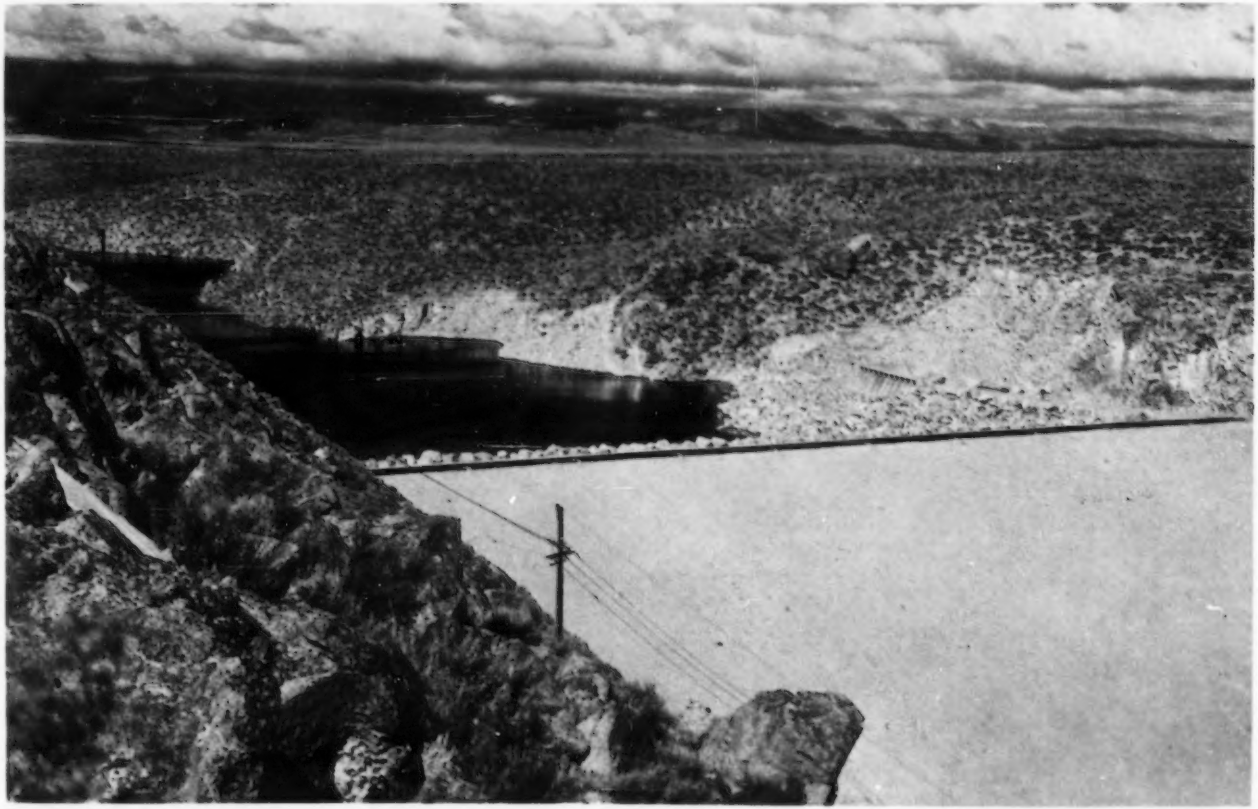

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Fig. 2. Long Valley Dam showing the downstream face of Long Valley Dam and the spillway structure.

the aqueduct intake. This provides an ideal situation of having large storage capacity above the Gorge and adequate storage capacity above the aqueduct intake. These conditions make it practical to utilize required flows for peaking at power plants in the Gorge while providing control for flows below Tinemaha to meet aqueduct capacity requirements.

Economic studies were made to determine the best number and locations of hydroelectric plants to develop the full available head. The most economical solution, considering available sites and costs of construction, operation and maintenance of tunnels, penstocks, surge chambers, diversion dams and power plants was found to be a three power plant arrangement, with the plants so located that the total head available was divided approximately equally between the three plants. The general topography of the area is such that the tunnels and penstocks could be run in nearly straight lines between the plants with the plants located at the bottom of the Gorge at about 1/3 points in elevation. These three plants have been designated Upper Gorge Power Plant (No. 1), Middle Gorge Power Plant (No. 2), and Control Gorge Power Plant (No. 3).

The upper power plant operates at variable heads due to fluctuations in water level in Lake Crowley, while the middle and control plants operate at constant heads about equal to the average head on the upper plant. All three plants pass substantially the same amount of water under all normal operating conditions. These conditions produce economies obtained by purchasing identical turbines, generators and other equipment for each of the three plants and requiring only one set of spare parts for major equipment which can be used in each plant. Owing to topographic conditions and the fluctuating water level in the lake, actual operating heads are only approximately equal. Studies of available water runoff and demands for delivery of water at Los Angeles combined with most favorable production of power resulted in full load design flow of 625 cu. ft. per second. The designs provide for an overload flow of 690 cfs as a maximum flow to be passed.

The general sequence of water flow starts with water being taken from Lake Crowley through a tunnel and penstock to the upper plant. A small after-bay receives the discharge from the upper plant and delivers water through a tunnel and penstock to the middle plant. A similar after-bay at the middle plant delivers water to the tunnel and penstock to the control plant. Provision is made to by-pass water down the present stream-bed around any tunnel, penstock or power plant. The by-passed water can be picked up at the next after-bay and passed through the other plants. The total amount of water passed through the plants is determined by the water demands in Los Angeles plus water applied to lands in the Owens Valley below the Gorge to replenish groundwater for later pumping into the aqueduct to Los Angeles during dry cycles of years.

The long time runoff records indicate that all of the water available from Mono Basin and the Owens River will be insufficient to utilize the full aqueduct capacity of 440 cu. ft. per second and thus meet the water demand of Los Angeles for as many as 13 dry years in a row. Pumping from groundwater in the Owens Valley will be required during such a long dry period. The City has more than 100 wells for this purpose in the Owens Valley.

Another problem of water control is involved in court decisions which have held that Los Angeles must so operate its aqueduct system as not to waste waters unnecessarily into Owens Lake, which is at the lower end of Owens Valley. Prior to diversions by the Los Angeles Aqueduct, this saline lake received all the residual flow of Owens River. Since that time chemical

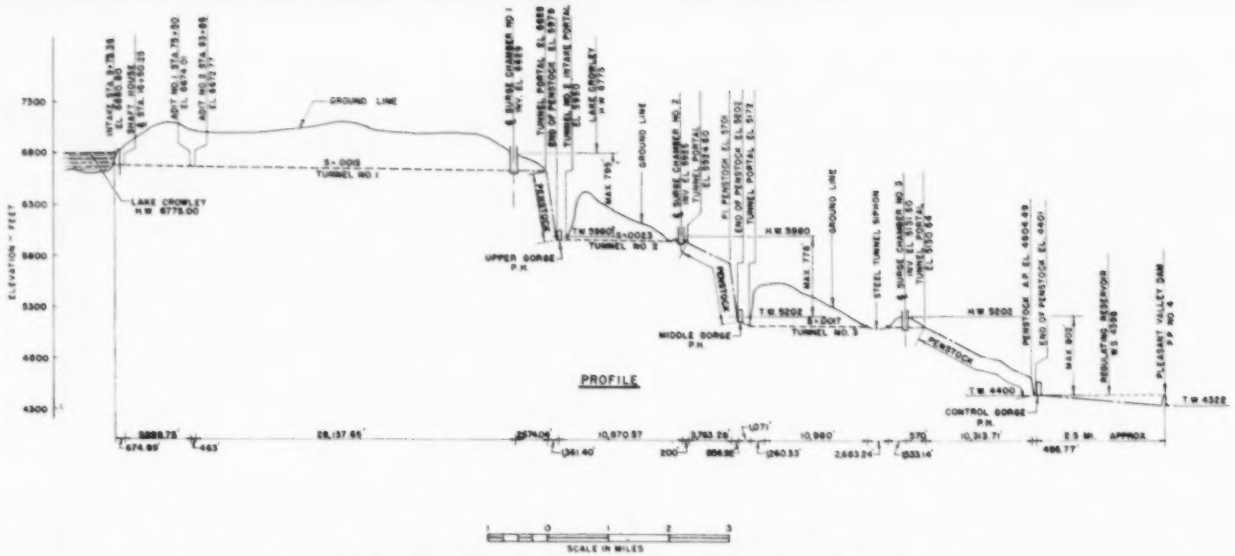

Fig. 3. Profile showing relative elevations of major units of the project.

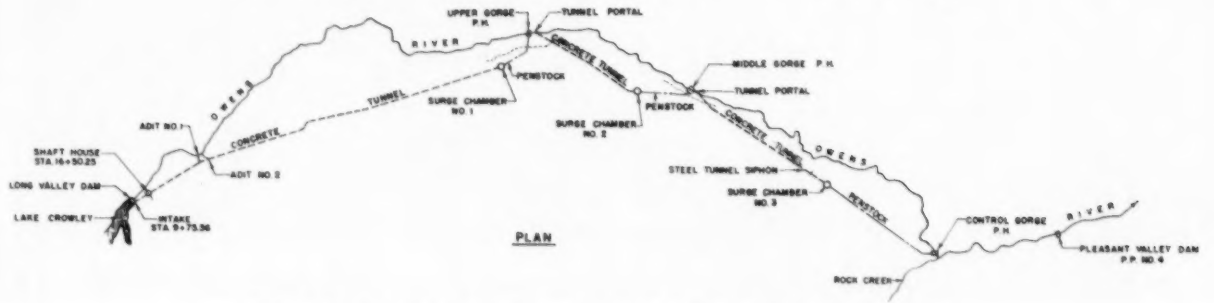

Fig. 4. Plan showing relative locations of major units of construction.

companies have found it more profitable to work the dry salt bed. In some flood years streams naturally tributary to the Owens River will exceed the capacity of our storage and diversion works and water will of necessity waste into Owens Lake. Water is diverted into the Aqueduct from streams which are naturally tributary to Mono Lake but, not naturally tributary to the Owens River and the Aqueduct system. Therefore it is important that careful water control methods be followed and our storage facilities so utilized that water will not be discharged into Owens Lake in excess of normal flood flows from streams naturally tributary to the Owens River, in excess of the capacity of the Owens River aqueduct to divert to Los Angeles.

Tunnels, Surge Chambers and Penstocks

In connection with Long Valley dam, a horseshoe-shaped outlet tunnel 6,575 feet long had been constructed many years ago. It was found necessary to install a 104 inch diameter welded steel liner, 1/4 inch thick, in this tunnel to safely withstand design pressures and eliminate water losses. The space between the liner and the tunnel was filled with cement grout. The latest construction program extended this tunnel 31,300 ft. to the rim of the Gorge above the Upper power plant. This and each of the other new tunnels are 10 ft. 1 1/4 in. inside diameter for most of their lengths.

Because of the extent of volcanic tuff anticipated in this tunnel, it was decided to investigate the modulus of elasticity to determine its ability to withstand internal water pressures without yielding to such extent as to cause cracking in an unreinforced concrete lining. This was ascertained first, by measurements of rock deflections by use of hydraulic jacks on a full size unlined tunnel section, and second, by constructing a full size test section of unreinforced concrete lined tunnel, applying internal hydrostatic test pressures and observing lining deflections. The conclusions were that in this type of material fully reinforced lining should be used.

This tunnel was driven from two headings. The material excavated during driving the tunnel varied from hard granite, basalt, hard rhyolite, and morainal material to soft volcanic ash. All but 10,600 feet of the tunnel was in dry material.

Designs for supporting the tunnel excavation and reinforcing the lining were developed for various conditions; typical designs are shown in the figures. The concrete lining in this tunnel is fully reinforced for maximum design pressures. At the downstream end of the tunnel the lining is designed for a static head of 176.50 ft. plus 4412 feet maximum surge, or a gross head of 220.62 feet. The tunnel grade is 1.5 ft. per thousand. The maximum overburden above this tunnel is 650 feet. The problems of driving this tunnel will be described later.

Tunnel No. 2 is 11,071 feet long and Tunnel No. 3, 11,564 feet long. These tunnels start from the after-bays at the upper and middle power plants. Tunnel No. 2 has a slope of 2.3 feet per thousand in order to pass under a small canyon near its downstream end. Tunnel No. 3 has a slope of 1.5 feet per thousand. Both tunnels No. 2 and No. 3 emerge from the ground on the mesa some distance back from the rim of the Gorge. Tunnel No. 2 was excavated through 3500 feet of granitic materials. The balance of this tunnel and all of Tunnel No. 3 were excavated through volcanic materials. All tunnels are of the same size and of similar design to Tunnel No. 1. From the south end of Tunnel No. 3 the conduit line crosses a small valley by means of a siphon 2641 ft. long and then enters a short tunnel 2103 ft. long. Except for 1950

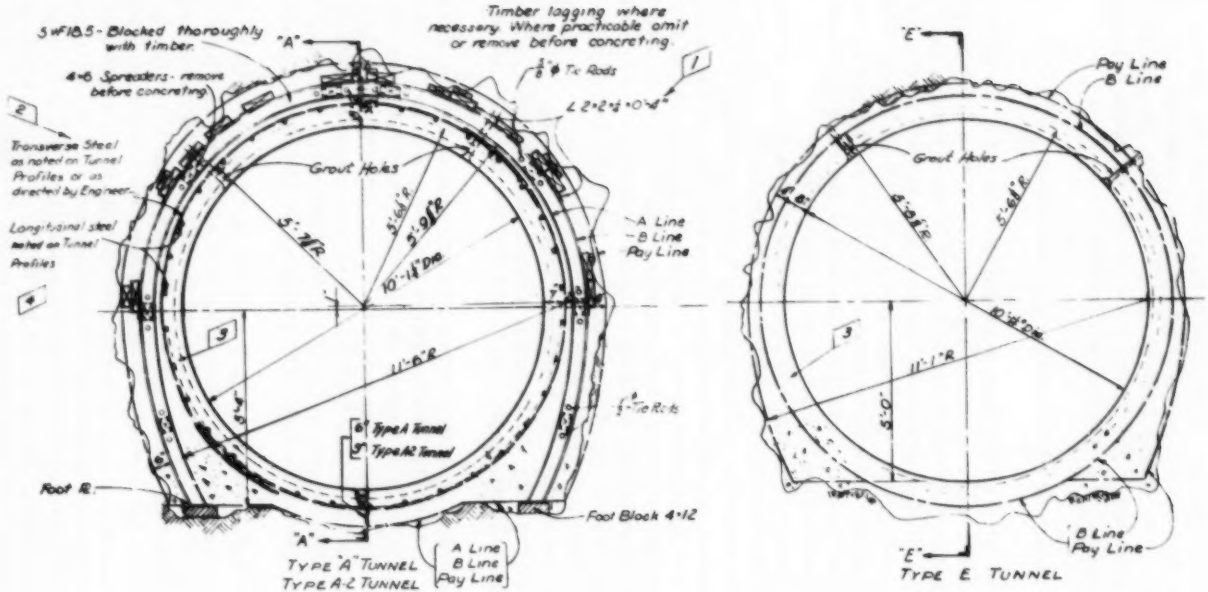
5 WF 18.5 - Blocked thoroughly with timber
4"x6" Spreaders - remove before concreting
Timber lagging where necessary. Where practicable omit or remove before concreting.
Transverse Steel as noted on Tunnel Profiles or as directed by Engineer.
Longitudinal steel noted on Tunnel Profiles
Grout Holes
A Line
B Line
Pay Line
Roof R.
Foot Block 4"x12"
TYPE "A" TUNNEL
TYPE A-2 TUNNEL
TYPE E TUNNEL

Fig. 5. Tunnel Sections showing a section requiring steel supports and reinforced concrete lining and a section requiring no supports and unreinforced concrete lining.

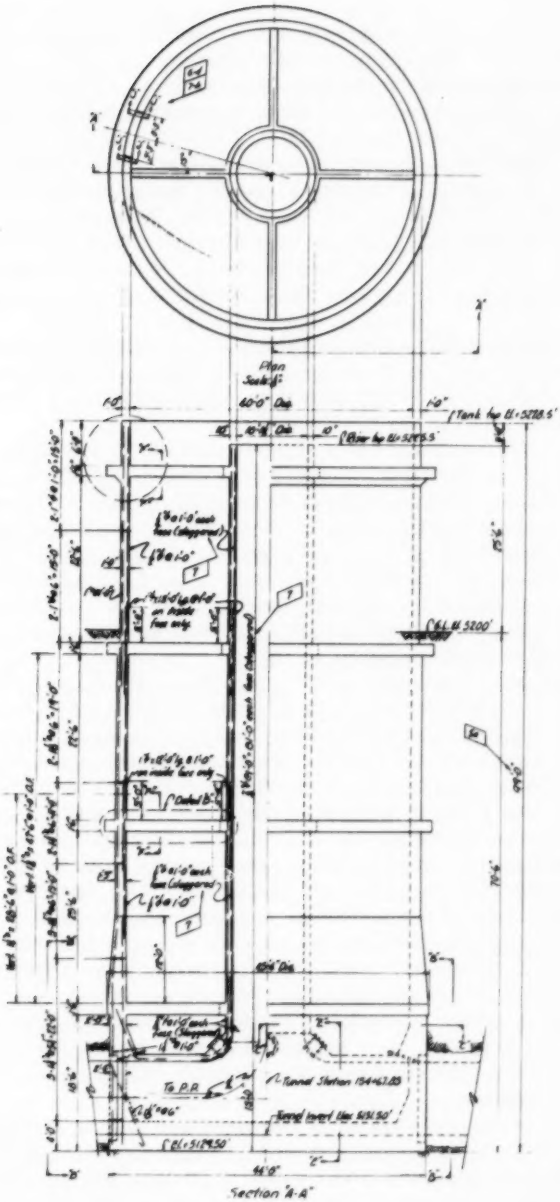

Fig. 6. Surge Chamber showing details of the differential type surge chamber.

feet of good granite in Tunnel No. 2 which permitted the use of unreinforced concrete lining, all of the concrete tunnel linings were reinforced for the full maximum design heads.

Each of the tunnels has an open surface surge chamber near the downstream end to improve the stability of the hydraulic system and to provide a means of limiting the effects of surges and water hammer. Differential type surge chambers were adopted because of their economical design. They consist of an outer chamber, an inside riser 10 ft. 1 1/4 in. inside diameter, the same as the tunnel diameter, and ports near the bottom which connect the outer chamber with the tunnel. The ports in surge chamber No. 1 are 2 ft. 0 in. in diameter and in surge chambers No. 2 and No. 3 the ports are 2 ft. 6 in. in diameter. The outer chamber of surge chamber No. 1 is 30 ft. inside diameter and 202 ft. 6 in. high; surge chamber No. 2, 40 ft. inside diameter and 80 ft. 6 in. high; and surge chamber No. 3, 40 ft. inside diameter and 99 ft. high.

The conduit system from the downstream tunnel portals to the power plants consists of steel penstocks. The diameter and thickness of plate of the penstocks varies from 106 inches by 3/8 inch at the upper ends to 92 inches by 1-1/6 inch at the lower ends at the power plants.

Penstock No. 1 is 1340 ft. long; No. 2, 4600 ft. and No. 3, 13,420 ft. The total length of penstock is 19,360 ft. Designs provided for all electric welded construction in shop fabricated sections of 30 to 40 ft. in length. The penstock sections were welded by the shielded arc process from plates requiring one longitudinal seam and two or more girth seams. Eight inch butt straps of the same thickness as the penstocks were used in the field girth joints. Full fillet welds were required on the butt straps as well as butt welds at the 60° beveled ends of the pipe sections. Half circle butt straps were used so as to provide for easier field assembly.

Where the static head is less than 185 ft., structural grade, A-283 grade B steel was used and, for higher heads, high strength, A-212 grade B steel. All angles in the penstocks, both vertical and horizontal, were made at anchor points providing straight sections at uniform grades between anchors. Anchor points are spaced at approximately 600 ft. intervals on the inclined sections of penstocks 1 and 3. Part of penstock No. 2 is in an inclined shaft which has been backfilled with concrete after the penstock was placed.

Where the penstocks are installed on the mesa and the slope is not too steep, ring girder supports are used between anchors. The ring girder and rocker type of support permit the penstocks to expand and contract freely without creating abnormal stresses and with no resistance other than at the rockers and that in the expansion joints. The ring girders are 8 inch "H" sections located at 60 ft. intervals and welded around the pipe. Each ring has two leg extensions resting on rocker supports. These rings prevent distortion of the pipe and permit it to be supported as a continuous beam. On the inclined sections, the supports are of the concrete saddle type, spaced at approximately 30 ft. intervals.

Expansion joints are located just below the upstream anchor of each section of penstock. A 600 ft. section of penstock will expand approximately 6 inches between minimum and maximum anticipated temperatures. The installation is in an area where temperatures fall as low as 30° below zero and rise as high as 110° above zero. The expansion joints are full penstock size and are of stainless clad steel with wax impregnated flax packing.

A Venturi is installed in each penstock for measurement of water flowing

to each plant. The Venturi sections are of stainless clad steel and are not bitumastic lined. Otherwise all penstocks are shop-lined with bitumastic enamel inside and one coat of red lead and one of white enamel outside. Exterior aluminum paint was applied in the field. The interior of all field joints was coated with bitumastic enamel in the field.

At the middle plant the lower portion of the canyon wall is almost vertical and the upper portion unconsolidated volcanic ash. These conditions made it very difficult to design a surface penstock for this location. Therefore a 45° incline tunnel was provided from the top of the canyon to the power plant and, the penstock was installed in this tunnel and concreted in place.

At each plant a wye branch is installed in the penstock with one branch serving the turbine and the other a bypass and relief valve. The wye branch will permit full flow of water through a plant when the turbine is not operating. Butterfly valves are installed ahead of the turbine and the relief valve at each power plant.

There is a 54-inch roto type valve located in the outlet tower from Lake Crowley which has been used to regulate the water discharged from the lake prior to construction of the power plants. An additional roto-valve has been installed at the transition from Tunnel No. 1 to penstock.

Power Plants

The three power houses are of similar open-air design except that the control house at the control plant is somewhat larger than those at the other plants. The power plants have plan areas approximately 60 x 90 feet. The bottom of the foundation is approximately 45 ft. below the generator deck. There is no superstructure above the generator deck which is approximately at ground level except the control house and crane rail supports.

The generator deck serves as the door over the turbine room and the rooms for housing pumps, switching equipment, battery chargers, compressors, and other small accessories. For use in construction and future overhauls each power plant is equipped with a 150 ton bridge crane having a 25 ton auxiliary hook. Permanent outdoor crane rail supporting structures are provided.

Turbines and Hydraulic Equipment

Each of the three hydraulic turbines has a rating of 51,200 h.p. when operating at 743 ft. head and discharging 689 cu. ft. per second. Normal speed is 400 r.p.m. These turbines have been designed to operate over a relatively wide range of head due to the variable water level in Lake Crowley. Maximum efficiency is at 585 c.f.s. at a head of 743 ft. The turbines are of the vertical shaft single runner Francis type with cast steel spiral casings and stainless steel runners identical in design, with all parts interchangeable. The turbines are so constructed that the runners can be removed downward through a removable section of the draft tubes. The shafts are hollow to pass cables from the overhead crane for installing and removing the runners. The upper section of the draft tubes are constructed in two pieces, each equipped with car wheels to permit removal sideways on a rail track. The lower piece is provided with two access doors for inspection and the top piece acts as a handling car for moving the runners. Both pieces are of cast steel with a stainless steel liner immediately below the runner. The draft tubes below the removable sections are lined with steel plate and have a 90 degree bend

Fig. 7. Timber Supported Section

Fig. 8. Steel Supported Section

so the water is discharged horizontally from under the building.

The turbine casings are of cast steel of spiral type designed for a hydrostatic pressure of 125% of maximum static pressure and have been shop tested at 200% of maximum static pressure. The casing and speed ring are integral and have been cast in two sections. Each turbine runner is a single piece casting of 18-8 stainless steel fitted with replaceable monel metal wearing rings. To meet the requirements of normally operating without an attendant, all features of the turbines have been given careful consideration for automatic and supervisory control operation.

The turbine shafts are made of forged open hearth alloy steel, heat treated. The shafts are hollow, 11 ft. 8-1/4 in. long, machined outside and inside to an outside diameter of 20 in. and an inside diameter of 5 in. The main turbine guide bearings are located above the runners and are of the babbit lined oil lubricated type with removable shells. The bearing shells are split vertically into two sections to facilitate dismantling. The bearings are lubricated by a forced circulation system with oil delivered under pressure to the top and bottom of the bearing cases.

The wicket gates and gate stems are integral 18-8 stainless steel castings. Each stem has three bronze bushing guide bearings and adjustable bronze bushing thrust bearing. The entire operating mechanism for controlling the wicket gate positions is mounted outside the turbine casing. All bearings on the wicket gate stems, gate shifting rings and levers are lubricated by an automatic pressure grease pump.

Removable and renewable wearing rings are provided at locations where there are close running clearances between the runners and stationary parts. Adjacent rings are of dissimilar non-corroding material.

Each turbine has two oil pressure operated double acting hydraulic cylinder servomotors having a combined capacity sufficient to operate the turbine wicket gates and the bypass valve. The two cylinders are so located that the force for moving the wicket gates is approximately equally divided and applied in approximately equal magnitudes on opposite sides of the gate shifting ring. Oil pressure for operating the servomotors is controlled by the governors.

A bypass valve is installed with each turbine in a separate branch of the penstock. These valves are hydraulically operated and controlled by the governors and can be adjusted to operate either as synchronous bypass valves or as automatically controlled relief valves. Energy absorbers are provided with each bypass valve for dissipating the energy in the jets from the valves before the water enters the tail race channel, and have a capacity to dissipate 51,200 h.p. The discharge passage from the energy absorbers to the tail race is steel lined. The valve bodies and energy absorber bodies are of cast steel, and the stationary and movable seats of the valves are of stainless steel.

Each turbine is controlled by a governor of the oil pressure relay valve actuator cabinet type with electrically driven speed responsive elements. The governors are adaptable for automatic synchronizing and automatic load and frequency control. The speed responsive element of each actuator is driven by an alternating current motor receiving its power supply from an independent self-excited alternating current generator mounted on the main generator shaft. The speed responsive elements are responsive to less than 1/100th of 1% of normal speed. The governor system is designed to permit a minimum gate opening or closing time of seven seconds.

A butterfly type shutoff valve is installed in each branch of the penstocks in the power houses, one ahead of the turbine and the other ahead of the bypass valve. The turbine shutoff valve is 78 in. inlet and 58 in. outlet and the

bypass shutoff valve is 56 in. inlet and 42 in. outlet. The normal operating head on these valves is 822 ft. and the maximum head 1,028 ft. The valves have steel bodies and discs and horizontal forged steel shafts carried in removable bushed bearings. The valve seats consist of removable monel metal seats on the discs and removable bronze seats on the bodies which are adjustable from the outside. The valves are designed to pass 725 cu. ft. of water per second and to close under full discharge conditions.

Generators and Electric Equipment

Each of the three generators has a rating of 37,500 kva, unity power factor, 3 phase, 60 cycle, 11,500 volt, 400 r.p.m., 60 degree rise and will carry a 15% overload without exceeding a temperature rise of 80 degrees centigrade. The guaranteed efficiency is 97.5%. Thrust bearings are of the Kingsbury type.

The step up transformer bank at each plant consists of three single phase, 12,500 kva, 11,000 volt delta to 235,000 volt "Y," oil immersed, forced air cooled transformers. An oil circuit breaker is installed at each terminus of the 230 kv transmission line from the Gorge project to Los Angeles. Each breaker is 3 pole with a rating of 230 kv, 800 ampere, and a rated interrupting capacity of 2,500 m.v.a. and an interrupting time of 5 cycles. The transformer bank at the terminus of the transmission line in Los Angeles consists of 3 single phase autotransformers having a high voltage rating of 220 kv "Y," a low voltage rating of 132 kv "Y" with a tap for 115 kv "Y" and a tertiary winding at a voltage rating of 13.2 kv delta suitable for operating a synchronous condenser. The high voltage winding has a rating of 30,000 kva self-cooled and 40,000 kva forced air cooled. Provision is made for increasing the capacity by one-third at some future date by the addition of supplementary forced-air cooling equipment when additional power may be transmitted over the line. These ratings provide a transformer bank capacity of 90,000 kva self-cooled, 120,000 kva forced-air cooled and provision for increasing the capacity to 150,000 kva.

Normal control of the three plants is from a control room at the control plant by a combination of direct wire, supervisory control and certain automatic features. In addition to the remote control each plant has a conventional control board for local control. The machines are started by remote manual control, synchronized and put on the line automatically, and then switched to automatic control. This control system maintains the same flow through each plant and maintains the desired water elevations in the tail bays.

For a change in the rate of flow the wicket gates and bypass valve setting at the upper plant are changed by the operator at Control Plant adjusting a control switch. The flow through this plant is measured by the Venturi meter in the No. 1 penstock. The indication of this meter is transmitted to the middle plant and balanced against indications from a similar meter in No. 2 penstock. Impulses from these meters operate on the wicket gates and bypass valve in the middle plant until the readings of the two Venturi meters are balanced. A similar set of meters and controls adjust the flow through the Control Plant until it balances the flow through the middle plant. Level controls for the No. 1 and 2 tail bays adjust the rates of flow to maintain the desired tail bay levels. The conditions which may be imposed on the control are infinite in number but may be said to fall in the following general categories: Load pick-up, either rapid or gradual; steady state running; and load rejection, either rapid or gradual. In addition to the automatic control each

turbine can be controlled separately from the control plant or independently from its local control board.

Transmission Line

A total of 600 million kwh per year at a maximum rated capacity of 112,500 kw made available from the three plants can be transmitted to Los Angeles over a 230 kv single circuit steel tower line approximately 260 miles in length. Tower design is based on a maximum loading of 1/2 inch of ice and coincident transverse wind load of 8 pounds per square foot of projected area. Suspension towers are capable of withstanding one broken conductor or one broken ground wire under this condition of loading. Maximum conductor tension will be approximately 10,000 pounds under medium loading conditions. Typical suspension towers are 102 ft. high, 30 ft. wide at the base with crossarms 86 ft. from the ground which provide for 26 ft. horizontal spacing of conductors. The conductor is 954,000 circular mills ACSR. (aluminum conductor steel reinforced) having a diameter of 1.196 inches, which was found desirable in reducing corona losses, particularly at the 6,700 ft. maximum elevation of the line. Sixteen 5" x 10" insulators are used in the suspension strings with double strings of 17 units at all strain positions. The line is protected by two overhead steel ground wires and counterpoise where tower footing resistance is above 100 ohms. Approximately 26 miles of line required counterpoise.

Construction

Department of Water and Power crews had constructed access roads, built camps and power lines, and had assembled some equipment and initiated construction before construction contracts were awarded. Mr. William C. Mason, member of A.S.C.E., served as Project Engineer for the Department.

A contract for construction of the tunnels was awarded May 19, 1949 to the Owens Tunnel Contractors composed of Guy F. Atkinson Company, Bressi & Bevanda Constructors, Inc., A. Teichert and Son, and David A. Gordon under the general management of Mr. Vincent Bressi.

Other than in tunnel driving involving wet ground, the contractors made excellent progress. The best tunnel driving records were obtained in the consolidated volcanic ash or tuff which, when dry, stood without supports. The section without supports was 12-1/2 ft. in diameter and 13-1/2 ft. where steel supports were required, the finished inside circular cross-section being 10' 1-1/4" in diameter, providing 80 sq. ft. of net area. The maximum records established were: 8 hr. shift, 41 ft.; 24-hour day, 104 ft.; 31 working days, 2,142 ft. The work was prosecuted on a 3-shift, 6-day a week basis. All headings were driven with jumbos, each carrying five Ingersoll-Rand D. A. 35 drifter drills provided with power feeds and mounted on 48" aluminum shells. The total tunnel length of 55,800 ft., or slightly more than 10-1/2 miles, was driven from five headings. Tunnel No. 1, driven from two headings, was 31,300 ft. long and the other tunnels, driven from single headings, were 10,900 ft., 11,500 ft., and 2,100 ft. There was also a 700 ft. long tunnel driven on a 45° slope for Penstock No. 2 for the Middle Plant.

In the north heading of Tunnel No. 1 the contractors first encountered water in the volcanic tuff which was difficult to hold when wet. They proceeded with steel supports and extensive use of lagging. After driving 9,880 feet a severe run-in occurred which filled the tunnel with muck about 10 ft.

deep at the heading, tapering to zero 400 feet back. At this point the contractors claimed "changed conditions" and shut down the work on this heading pending action on various requests made by them.

During this period there were many conferences and discussions regarding methods for progressing the excavation through this material. The contractors proposed to use an extensive grouting operation ahead of the face while the Department's engineers favored using conventional tunneling methods including the driving of spiling and using breastboards where necessary. The latter method was used to a successful conclusion.

The contractor was finally permitted to excavate a "dog-leg" around the original tunnel alignment which had a cavity at the heading perhaps 50 feet above the tunnel grade. This "dog-leg" has a length of 4,724 feet and involved the abandonment of 719 feet of tunnel previously driven. It was agreed that the work should proceed and decision be made at a later date as to whether the Department or the Contractor was financially responsible for the tunnel constructed but abandoned and the additional length of new tunnel.

The 10,619 feet of wet tunnel consisted of 4,750 feet in volcanic tuff, 5,619 feet in alluvial materials including boulders and 250 feet in hard rock. It required 21 months to drive from the time water was first encountered until completion of the wet section, or 11 months from the beginning of the "dog-leg" to completion of the wet section. During this period the contractor worked three shifts per day and during most of the time from two headings.

The following table shows comparison of best progress in dry tuff in North Tunnel No. 1 and in hard rhyolite in Tunnel No. 3.

	Tunnel No. 3	Tunnel No. 1
Total footage, 31 days*	2,204	2,442
Av. footage per day	71.10	78.77
Total excavation, cu. yd.	10,107	11,061
Best footage, 24 hr.	85	104
Best footage, 8 hr.	31	41
Total pounds powder used, 31 days	31,343	33,787
Total pounds powder per cu. yd.	3,101	3.055
No. rounds, 31 days	250	253
Av. length of rounds, ft.	9.74	10.97
Av. no. holes per round	35	31
Av. advance per round, ft.	8.82	9.65

*Tunnel No. 1 record, north portal, was made between 8:00 a.m., October 24 and 8:00 a.m. December 2, 1949; and Tunnel No. 3 record, south portal between 8:00 a.m. August 25 and 8:00 a.m. October 1, 1949.

A typical crew for all shifts was 1 walker, 1 shifter, 5 miners, 1 tool nipper, 5 chuck tenders, 1 mucking machine operator, 2 locomotive operators, 2 trainmen, 2 dump men, 1 compressor operator, 1 change house attendant, 1 electrician, and 1 mechanic. The day shift in the tunnel was augmented by 1 powder man and 1 "bull" gang, consisting of a foreman and 4 to 7 laborers. Dynamite used varied from 17% grade in the tuff to 45% in hard rhyolite.

Eighteen inch diameter steel pipe carried air for ventilation supplied by centrifugal blowers of 7,500 to 10,000 cu. ft. per minute capacity. Compressed air at 100 lb. pressure was carried in a 6" pipe and water in a 2" line. A 440 volt 3 phase cable supplied power for the mucking machines.

The steel penstocks were fabricated by the Consolidated Western Division of the United States Steel Corporation and by Southwest Welding and

Fig. 9. Upper Gorge Power Plant

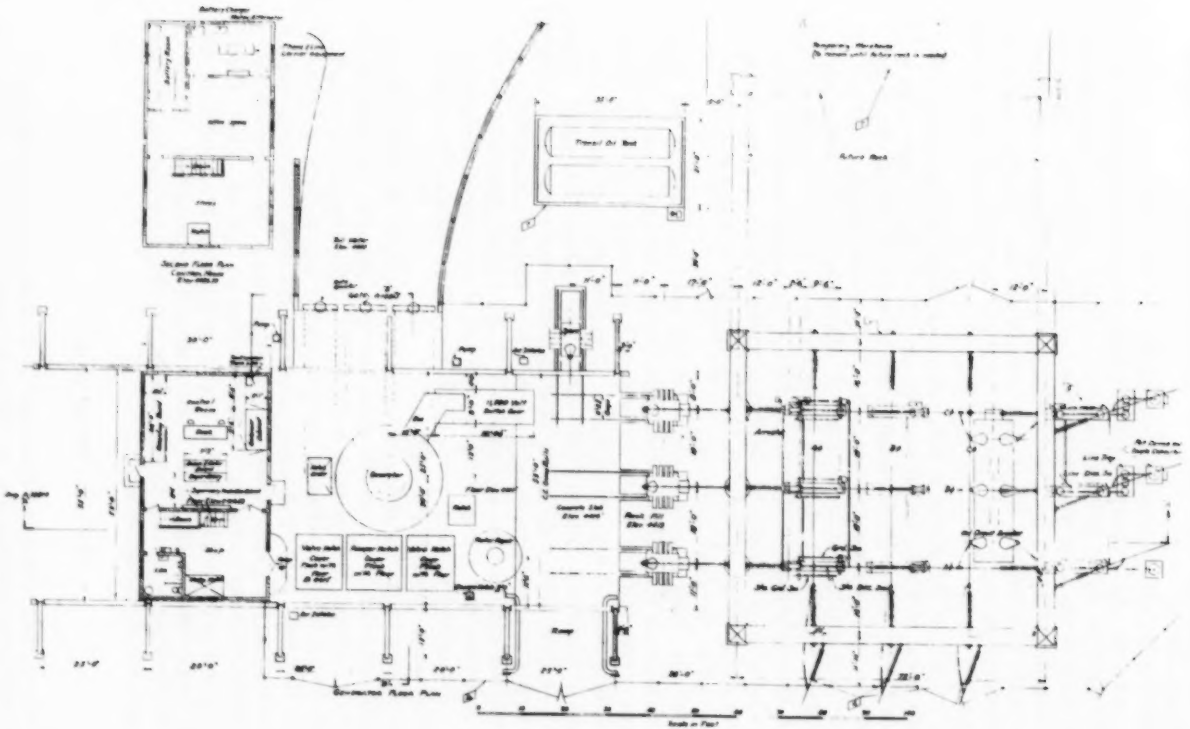

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Fig. 10. Power Plant Plan showing arrangement of Control Power Plant.

Manufacturing Company. The general contractor for field erection of the penstocks was Stanley H. Koller. The field erection contract was not progressed satisfactorily and was finally abandoned by the Contractor. The Department then took over this operation and completed the field erection with Department forces.

X-ray examination of some of the field welds revealed defective longitudinal shop welding. As a result of further examination the Department ordered 100% field X-raying of both the shop and field welds. The defective condition of some of the shop welding necessitated an unexpected operation wherein it became necessary for Department forces, with some assistance by the fabrication contractors, to remove and reweld the defective zones together with refinishing the interior enamel and the exterior painting damaged by this work.

The construction of the power houses and installation of equipment was done by Department of Water and Power forces. They also constructed a dam at Upper Gorge Power Plant creating the forebay for tunnel No. 2 and a reinforced concrete forebay for tunnel No. 3 at Middle Gorge Plant.

The steel transmission line towers were fabricated by the Bethlehem Steel Co. at their South San Francisco Shops and were erected by Department forces which have previously constructed all its transmission lines. The "Cardinal" aluminum conductor of 954,000 circular mills was furnished by the Aluminum Corporation of America with the stringing being done under contract awarded to Joe Bush Service.

Footings for the transmission line towers are predominantly of the pole type which consists of a reinforced concrete cylinder poured in an augered hole. In areas where the soil would not permit direct augering for the pole type footings, a system of soil stabilization by means of injection of a solution of sodium silicate and sodium bicarbonate was successfully used. Where other foundation conditions existed suitable footings were constructed. Paper forms were used for the concrete curb faces which resulted in savings in labor and form materials. The accessibility of the towers determined whether the concrete was delivered by mobile mixers or mixed directly at the job site. The nature of the terrain also determined whether the tower was erected by using a crane or a "gin-pole."

Joe Bush Service began its stringing operations on May 15, 1950. Its attempt to string the conductor under tension met with failure. Because of the unsatisfactory progress, the company subcontracted the remainder of the stringing operations to the Parker-Schram Company and to Lacy Electrical Construction. Although these sub-contractors did not progress their work at a rate satisfactory to the Department they, nevertheless, did complete the work which was finally approved by the Department on July 26, 1951. Controversies arose under this contract as to the condition of the conductor, and as to sagging requirements and other miscellaneous occurrences. These controversies resulted in claims by the contractors for additional payments which have not been resolved as yet.

Pleasant Valley Dam

The Department has under construction the Pleasant Valley Dam and power house located approximately 14,000 feet downstream from the Control Power Plant. High water in the reservoir created by this dam will back up to the Control Power Plant. The Pleasant Valley Dam will be an earth-filled dam 115 feet in height above lowest foundation and containing approximately

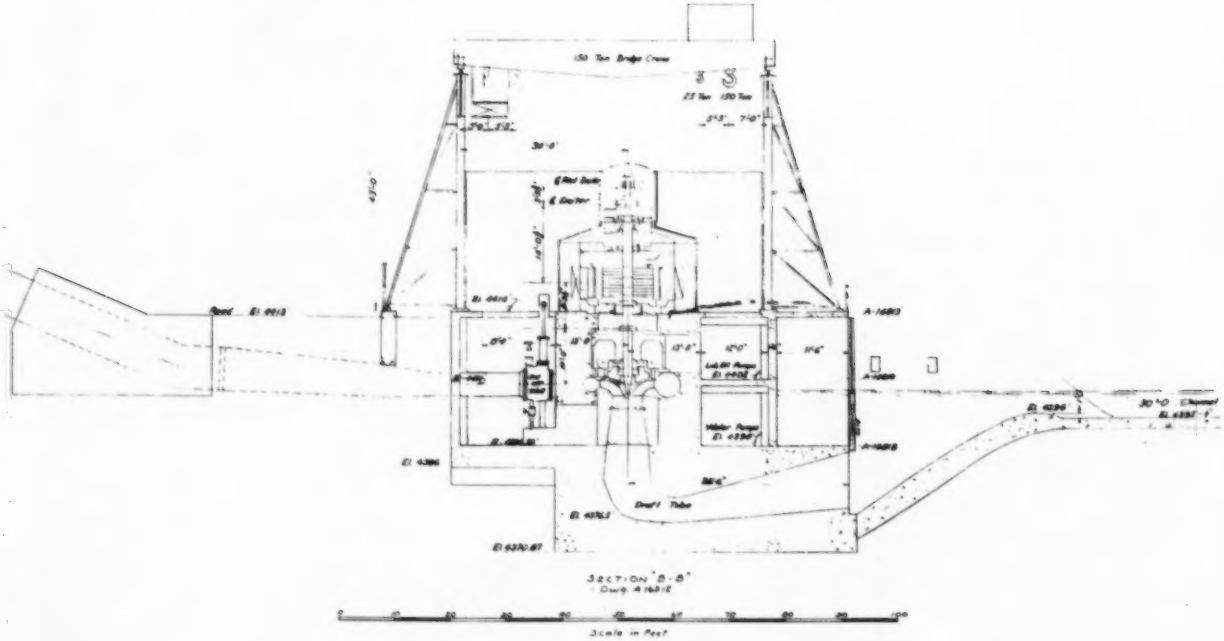

Fig. 11. Power House Section showing typical arrangement.

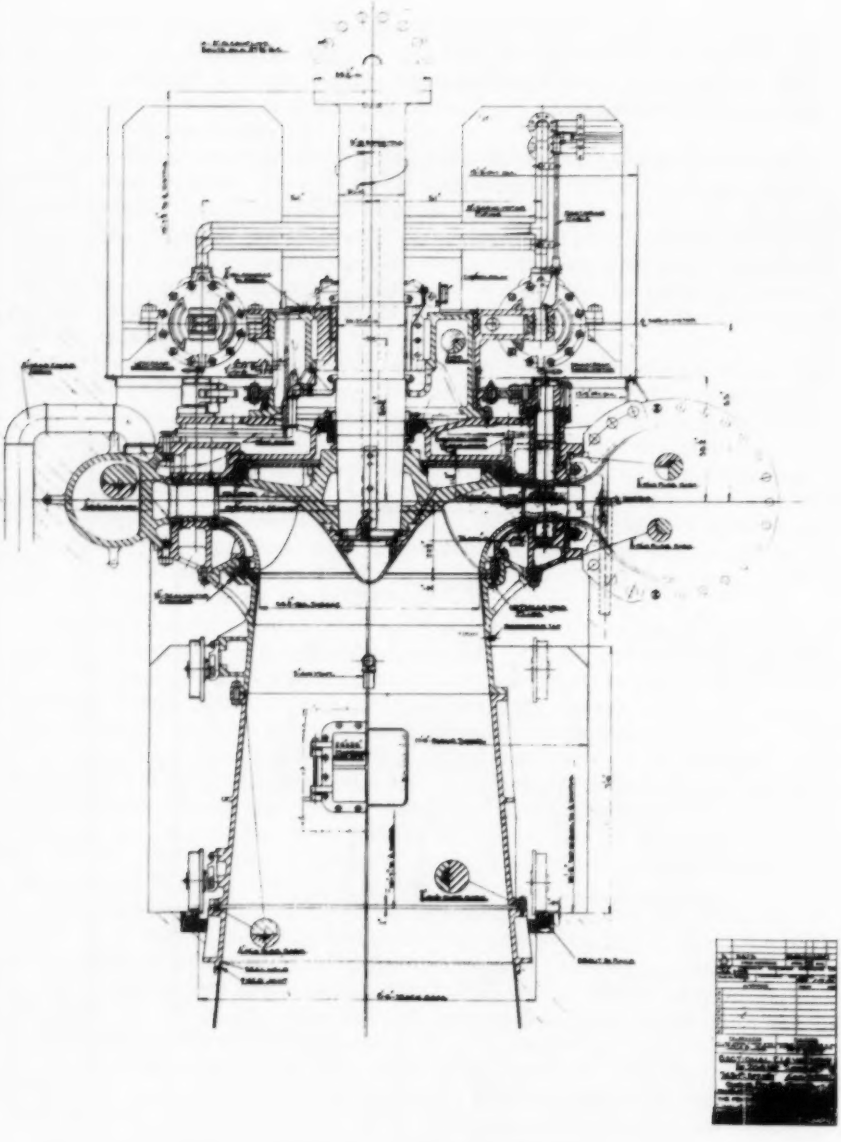

Fig. 12 - Turbine Elevation

440,000 cu. yd. The purpose of this dam and reservoir is to provide sufficient capacity to level out the daily variations in flow through the three power plants above it, permitting their maximum peaking capability. Normal release from this reservoir will be through a 4000 kw. hydroelectric plant at a more or less constant flow of water, so as to provide for minimum interference with fishing opportunities downstream and a more constant head for diversion of water from the natural stream channel to a number of canals

Fig. 13. Transmission Line Tower showing typical dead end tower.

downstream from Pleasant Valley Dam. The cost of this dam and power plant is justified by its integration into the total project by furnishing re-regulation storage necessary for the proper functioning and peaking opportunities of the three major 37,500 kw. installations.

Cost

The approximate cost of the Owens Gorge Project, including interest during construction, is substantially as follows:

Power Plants	$11,574,000
Tunnels	19,377,000
Penstocks	8,093,000
Transmission Line	10,541,000
Stepdown transformer bank and switches at Rec. Sta. "E"	1,331,000
Roads	682,000
Permanent housing and headquarters	675,000
Telemetering and communications	316,000
	$52,589,000
Pleasant Valley Dam and power plant estimate	3,000,000
Estimated total project cost	$55,589,000
To the above should be added expenditures prior to 1947 for power plants, land, rights, preliminary construction, and one-half of the Long Valley Dam charged to Power	4,423,000
GRAND TOTAL	$60,012,000

The justification of the project is that the low interest rates under which the financing was obtained together with the economy of semiautomatic operation requiring a minimum of operating personnel make the project competitive with present and prospective costs of fuel burning generating plants, and conserve irreplaceable fuel resources.

To deliver a domestic water supply of 318,000 acre feet per annum and 200,000 kw. of power, the Department has a total investment in its Owens River Aqueduct and power plants of approximately $150,000,000 of which more than $30,000,000 has been expended for lands and water rights in Inyo and Mono Counties.

The Owens Gorge Project design and construction was under the general supervision of Mr. James D. Laughlin in his capacity as Engineer in Charge of Design and Construction, and now Assistant Chief Electrical Engineer. Mr. Wm. S. Peterson was successively Assistant Chief Electrical Engineer and later succeeded Mr. Charles P. Garman as Chief Electrical Engineer and Assistant Manager. More recently Mr. Ivan L. Bateman has succeeded Mr. Peterson who has become Assistant Chief Engineer and General Manager

of the Department. The writer has been General Manager and Chief Engineer of the Department of Water and Power since 1944.

Consulting Engineers were: H. A. Van Norman, Charles T. Leeds, Carl R. Rankin, and Frederick J. Converse, Members, ASCE, and Chester Marliave served as Consulting Geologist.

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